International Journal of Scientific Research & Engineering Trends
Volume 12, Issue 1, Jan-Feb-2026, ISSN (Online): 2395-566X

Design And Structural Analysis Of Helical Gear With Varying Helix Angle

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Abstract- This study focuses on the design and structural analysis of helical gears with varying helix angles to investigate their influence on mechanical performance. By designing helical gears with different helix angles and analyzing them under identical loading and boundary conditions, the study aims to evaluate changes in bending stress, contact stress, deformation, and axial force. The results of this investigation will help identify optimal helix angle ranges that enhance gear strength and longevity while minimizing undesirable effects such as excessive axial loads and material failure. The findings of this study are expected to contribute to improved gear design practices by providing insights into the relationship between helix angle variation and structural performance. Such insights are valuable for engineers and designers seeking to develop efficient, durable, and high-performance gear systems for modern mechanical applications.

Keywords – Helical gear, helix angle, structural analysis, optimization.

I. INTRODUCTION

Gears are fundamental mechanical components used extensively in power transmission systems across a wide range of industries, including automotive, aerospace, manufacturing, and heavy machinery [1]. Among the various types of gears, helical gears are widely preferred due to their ability to transmit power smoothly and quietly at high speeds and loads. Unlike spur gears, helical gears have teeth inclined at an angle to the axis of rotation, known as the helix angle, which allows gradual engagement of teeth and results in reduced noise, vibration, and shock loading [2]. The helix angle plays a critical role in determining the performance characteristics of a helical gear. Variations in helix angle influence key parameters such as load distribution, contact ratio, axial thrust, bending stress, contact stress, and overall efficiency of the gear system [3]. A higher helix angle generally improves load sharing and smoothness of operation but also increases axial forces and manufacturing complexity. Conversely, lower helix angles reduce axial thrust but may lead to higher stress concentrations and less smooth engagement. Therefore, selecting an optimal helix angle is essential for achieving a balance between strength, durability, and operational performance.

Structural analysis of helical gears is vital to ensure reliable operation under varying load conditions. Traditional analytical methods, such as Lewis bending theory and Hertzian contact stress analysis, provide preliminary estimates of gear strength. However, these methods often involve simplifying assumptions that may not accurately represent real operating conditions [4]. With advancements in computational tools, finite element analysis (FEA) has become a powerful approach for evaluating the structural behavior of gears, enabling detailed analysis of stress distribution, deformation, and failure-prone regions under realistic loading scenarios. This study focuses on the design and structural analysis of helical gears with varying helix angles to investigate their influence on mechanical performance. By designing helical gears with different helix angles and analyzing them under identical loading and boundary conditions, the study aims to evaluate changes in bending stress, contact stress, deformation, and axial force. The results of this investigation will help identify optimal helix angle ranges that enhance gear strength and longevity while minimizing undesirable effects such as excessive axial loads and material failure. The findings of this study are expected to contribute to improved gear design practices by providing insights into the relationship between helix angle variation and structural performance. Such insights are valuable for engineers and designers seeking to develop efficient, durable, and high-performance gear systems for modern mechanical applications.

II. LITERATURE REVIEW

The study conducted by Gyungju and Kang (2026) successfully demonstrates the effectiveness of combining finite element analysis with experimental validation in the cold forging process of pinion gears with inner helical gears. The finite element model accurately predicted material flow behavior, stress distribution, and potential defect regions during the forging process, showing strong agreement with the experimental results. This validation confirms the reliability of

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the simulation approach for analyzing complex gear geometries such as inner helical gears, which are traditionally challenging to manufacture. The study by Abdulaal and Abdulah (2025) presents a comprehensive mathematical model and generation analysis for crossed helical gear systems, offering a clear theoretical framework for understanding their geometry and meshing characteristics. The developed model accurately describes the relationship between gear parameters such as helix angle, shaft angle, and tooth geometry, enabling precise prediction of contact conditions and kinematic behavior. Through generation analysis, the authors effectively demonstrate how crossed helical gears can be designed to achieve proper meshing and smooth motion transmission despite operating with non-parallel and non-intersecting shafts. The results provide valuable insights into contact patterns, transmission accuracy, and limitations related to load-carrying capacity inherent in crossed helical gear systems. This research enhances the theoretical understanding of crossed helical gears and serves as a useful reference for designers and engineers involved in low- to moderate-load power transmission applications. Overall, the study contributes significantly to gear design methodology by bridging mathematical modeling with practical generation analysis, supporting more accurate and efficient crossed helical gear system design.

The study by Roda-Casanova et al., (2025) provides a detailed investigation into the ISO 6336 face load factor and its applicability to helical gear systems. The authors critically analyze how face load distribution affects bending and contact stresses in helical gears and evaluate the adequacy of the ISO 6336 standard in predicting real load conditions. The study highlights that while the ISO face load factor offers a practical and standardized approach for gear design, its accuracy is highly dependent on factors such as gear alignment, manufacturing tolerances, shaft deflection, and bearing stiffness.

The study by Kadhim and Abdullah (2025) presents a comprehensive modeling approach and detailed contact stress analysis of crossed-axes helical gear systems. The authors develop an accurate geometric and analytical model to evaluate meshing characteristics and contact behavior between mating gear teeth operating on non-parallel and non-intersecting shafts. The contact stress analysis reveals the influence of key design parameters, such as helix angle, shaft angle, and load conditions, on stress distribution and contact patterns. The results show that crossed-axes helical gears experience localized contact and relatively higher stress concentrations compared to parallel-shaft helical gears, which limits their load-carrying capacity. The study by Patil et al., (2025) effectively demonstrates the application of the Taguchi method combined with analysis of variance (ANOVA) for the optimization of stress parameters in helical gears. By systematically varying key design factors such as helix angle, face width, module, and applied load, the authors identify their relative influence on bending and contact stresses. The statistical analysis reveals that helix angle and face width are among the most significant parameters affecting stress distribution in helical gears. The optimized design obtained through the Taguchi approach shows a noticeable reduction in stress levels, leading to improved strength and fatigue life.
The study by Chu and Chen (2025) presents a detailed investigation into the geometric design principles and fundamental feature characteristics of double helical face gears. The authors establish a comprehensive geometric model that accurately describes tooth surface generation, meshing conditions, and key design parameters unique to double helical face gear configurations. Their analysis demonstrates that the double helical arrangement effectively balances axial forces, leading to improved load distribution and enhanced transmission stability compared to single helical face gears. The study by Yao et al. (2025) investigates the influence of three-dimensional topology modification on the temperature distribution and thermal deformation behavior of internal helical gear pairs. Through detailed numerical analysis, the authors demonstrate that appropriate three-dimensional tooth surface modifications can significantly improve thermal performance by reducing localized heat concentration during meshing. The results show that optimized topology modification leads to a more uniform temperature field and effectively minimizes thermal deformation, which is critical for maintaining accurate meshing and reducing noise and vibration in internal helical gears.

III. RESEARCH METHODOLOGY

Research Method
The research adopts a computational and analytical approach to investigate the influence of helix angle on the performance of helical gears. Initially, three-dimensional CAD models of helical gears are developed using professional CAD software (such as SolidWorks or CATIA), with all geometric parameters kept constant except the helix angle, which is varied systematically. This ensures a fair comparison of gear behavior under identical conditions.

Subsequently, the CAD models are imported into a FEA software (such as ANSYS or Abaqus) for structural and static analysis. Appropriate material properties, boundary conditions, and loading conditions are applied based on standard gear design practices. The mesh is refined in critical regions, particularly around the gear tooth root and contact surfaces, to accurately capture stress concentrations and deformation behavior.

The analysis focuses on evaluating von Mises stress, contact stress, total deformation, and load-carrying capacity for each helix angle. Additionally, tooth contact patterns and load distribution are examined to understand the effect of helix angle variation on meshing behavior and load sharing. The results

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obtained from different helix angles are then compared under identical loading conditions to ensure consistency.

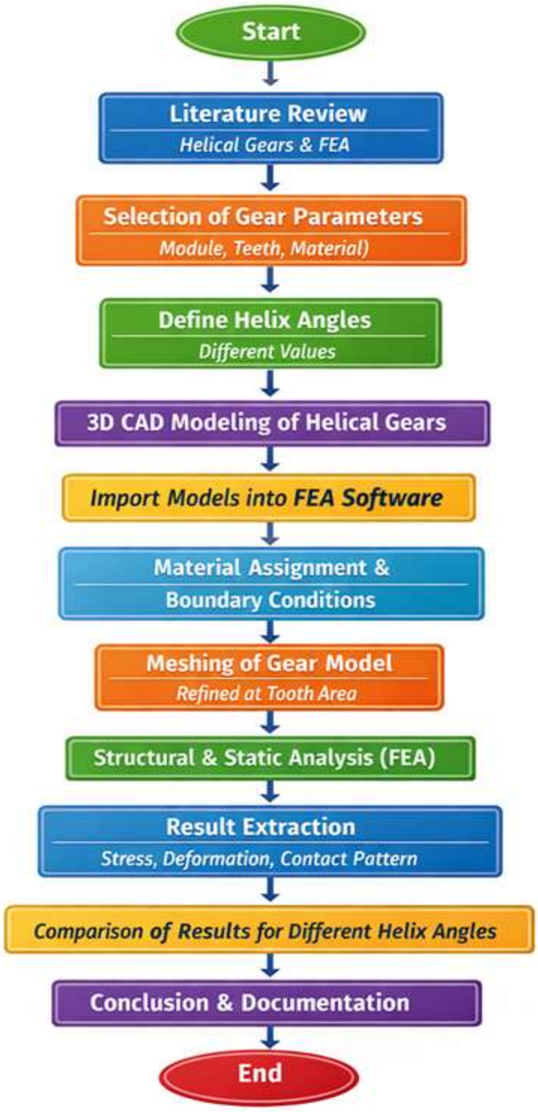

Fig. 1: Flow chart for simulation

Finally, a comparative assessment is performed to identify the optimal helix angle that offers maximum strength, minimum stress, reduced deformation, and improved transmission efficiency under identical loading conditions. The comparative results enable a clear evaluation of the influence of helix angle on stress distribution, load-carrying capacity, and tooth contact behavior. The findings significantly enhance the understanding of how geometric variations in helical gears affect durability, reliability, vibration characteristics, and overall mechanical performance. This comprehensive analysis provides valuable insights for gear design optimization, supporting the selection of appropriate helix angles to achieve improved service life, operational stability, and efficient power transmission in practical engineering applications.

Selection of Gear Parameters

The gear is designed to transmit a power of 20 kW at a rotational speed of 1440 rpm, which corresponds to a transmitted torque of 132.63 Nm. A pressure angle of 20° is selected as it is widely adopted in industrial applications for providing a good balance between strength and smooth meshing. The number of teeth is fixed at 25 to avoid interference and ensure proper engagement. A normal module of 5.18 mm and a transverse module of 5 mm are selected based on strength requirements and standard module availability. The helix angle of 15° is chosen as a moderate value to improve load sharing and reduce dynamic effects while limiting excessive axial thrust. The resulting pitch diameter of 129.5 mm and pitch of 16.27 mm satisfy the geometric and kinematic requirements of the gear system.

The face width of 72.86 mm is selected to enhance load distribution across the tooth surface and increase bending strength. Standard proportions are used for the addendum (5 mm) and dedendum (6.25 mm) to ensure adequate tooth strength and clearance. The calculated pitch line velocity of 9.76 m/s confirms that the gear operates within acceptable limits for safe and efficient performance.

Table 1: Dimensions of helical gear

S. No.	Parameter	Symbol / Unit	Value
1	Power	kW	20
2	Speed	rpm	1440
3	Number of teeth	Z	25
4	Normal module	mm	5.18
5	Pressure angle	°$\emptyset$	20
6	Helix angle	°θ	15
7	Transverse module	mm	5
8	Pitch diameter	mm	129.5
9	Circular pitch	mm	16.27
10	Addendum circle radius (Pa)	mm	60.72
11	Face width	mm	72.86
12	Pitch line velocity	m/s	9.76
13	Base circle diameter	mm	121.7
14	Addendum	mm	5
15	Dedendum	mm	6.25
16	Transmitted torque	Nm	132.63

Table 2: Design parameter of helical gear

S. No.	Variable name	Value	Description
1	Z	24	No. of teeth
2	D	129.5	Pitch diameter (mm)
3	P	16.27	Diametrical pitch (mm)

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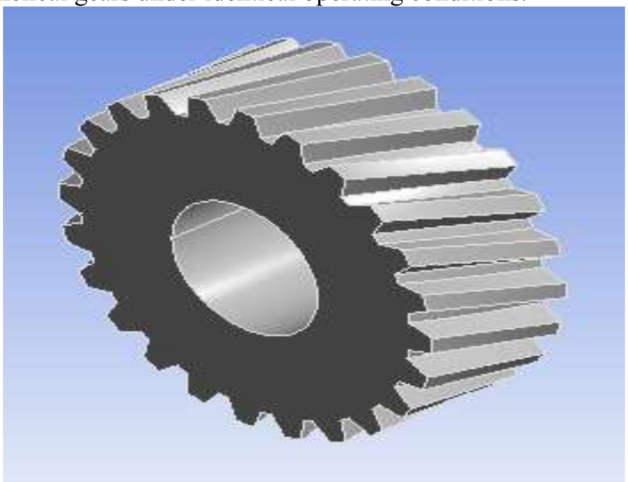
4	Ø	15°	Helix angle

Define Helix Angles

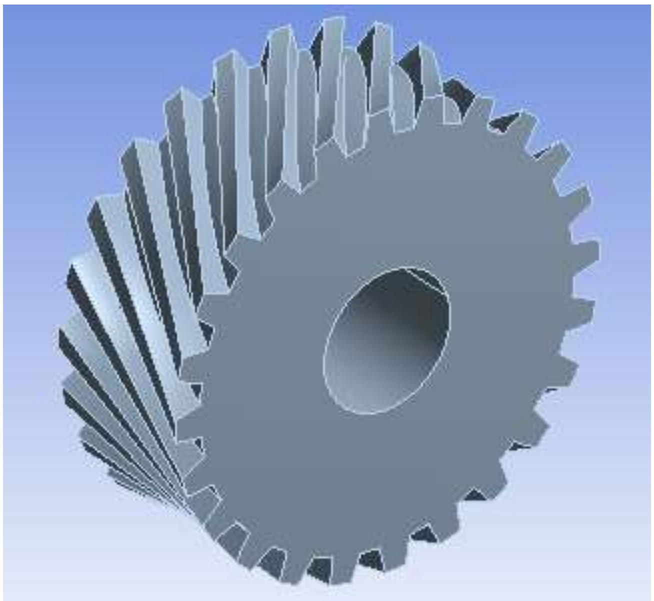
In the present study, the helical gear is modeled using SolidWorks to ensure accurate geometric representation and ease of parameter control. The base gear model is first created using the selected design parameters, and the helix angle is then varied systematically to study its effect on gear performance. Helix angles of 15° and 25° are considered, as these values are commonly used in industrial applications and provide a wide range for comparative analysis. For each helix angle, a separate 3D CAD model of the helical gear is developed in SolidWorks while keeping all other parameters—such as module, number of teeth, pressure angle, face width, and material—constant. This controlled variation ensures that any observed changes in stress distribution, deformation, or load-carrying behavior are solely due to the change in helix angle.

CAD Modeling of Helical Gears

To study the effect of helix angle on gear performance, the helix angle is systematically varied while keeping all other parameters constant. Separate CAD models are created for helix angles of 15° and 25°, ensuring consistency and enabling a fair comparative analysis. SolidWorks' parametric modeling capability allows precise control over the helix angle, ensuring accurate tooth orientation and uniform geometry across all models. Each gear model is carefully checked for geometric accuracy, proper tooth profile generation, and absence of modeling errors. The finalized CAD models are then saved in appropriate formats (such as STEP or IGES) for seamless import into finite element analysis software. These CAD models form the foundation for evaluating stress distribution, deformation, contact behavior, and load-carrying capacity of helical gears under identical operating conditions.



(a) 15°



(b) 25°

Fig. 1: CAD model of helical gears

Material Assignment

Material assignment is a crucial step in finite element analysis, as it directly influences the accuracy of stress, deformation, and performance predictions of the helical gear. In this study, the helical gear is assumed to be made of AISI 4340 alloy steel, which is widely used in gear applications due to its high strength, good toughness, excellent fatigue resistance, and suitability for heat treatment. The material properties are defined in ANSYS Workbench by assigning appropriate mechanical characteristics such as Young's modulus, Poisson's ratio, density, yield strength, and ultimate tensile strength based on standard material data. These properties ensure realistic simulation of the gear's elastic behavior under applied loads. The material is assumed to be homogeneous, isotropic, and linearly elastic for the purpose of static structural analysis.

Table 3: Material Properties of AISI 4340 Alloy Steel

S. No.	Property	Symbol	Value	Unit
1	Young's Modulus	E	210	GPa
2	Poisson's Ratio	ν	0.30	–
3	Density	ρ	7850	kg/m³
4	Yield Strength	σy	470	MPa
5	Ultimate Tensile Strength	σu	745	MPa
6	Shear Modulus	G	80	GPa
7	Hardness (Typical)	–	217	HB

The material is assumed to be homogeneous, isotropic, and linearly elastic, which is appropriate for static structural analysis. By manually entering these material properties,

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consistency and control over the simulation parameters are maintained, ensuring reliable stress and deformation results. This accurate material definition forms a critical foundation for evaluating the structural behavior and performance of the helical gears with different helix angles.

Boundary Conditions

Boundary conditions are applied in ANSYS to accurately represent the real operating constraints and loading conditions of the helical gear during finite element analysis. Proper definition of boundary conditions is essential to obtain realistic stress distribution and deformation results. In this study, the helical gear is analyzed under static structural conditions. The gear hub or inner bore is constrained by applying a fixed support, restricting all translational and rotational degrees of freedom to simulate the gear being rigidly mounted on a shaft. A torque or tangential load corresponding to the transmitted power is applied to the gear teeth or pitch circle to represent actual operating conditions. This loading simulates the force transmitted during gear meshing.

Additionally, appropriate contact definitions are established between the meshing tooth surfaces to ensure realistic load transfer and contact behavior. Frictional or frictionless contact is selected based on analysis requirements. All boundary conditions are applied consistently for each helix angle to ensure a fair comparison of stress, deformation, and load-carrying capacity. These carefully defined boundary conditions allow accurate evaluation of the structural performance of the helical gears under identical working conditions.

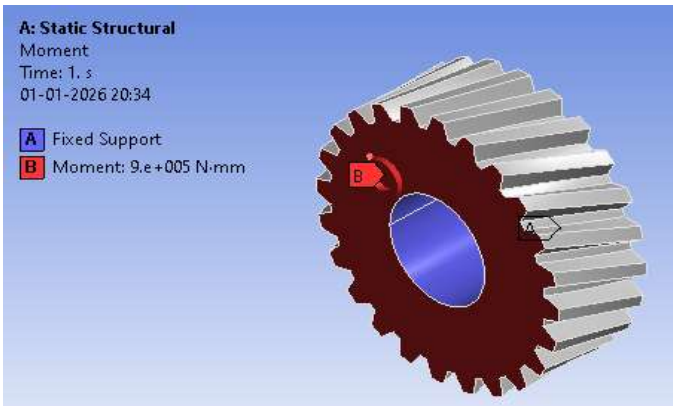
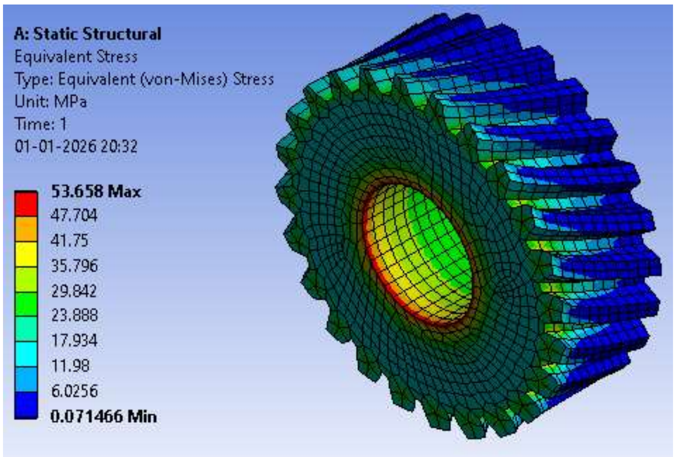


Fig. 2: Boundary condition applied

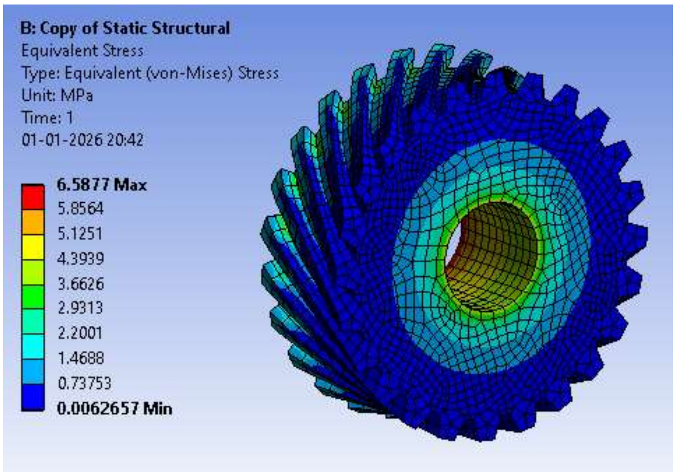
IV. RESULTS AND DISCUSSION

Stress Analysis

Stress analysis is a critical aspect of helical gear design, as it directly influences the strength, durability, and reliability of the gear system under operating conditions. In helical gears, stresses primarily occur in the form of bending stress at the tooth root and contact stress on the tooth flank due to the transmitted load. Because of the inclined tooth geometry and the presence of both rolling and sliding contact, the stress distribution in helical gears is more complex than in spur gears. The gradual engagement of teeth and higher contact ratio generally result in better load sharing; however, improper design parameters, misalignment, or mounting errors can lead to stress concentration and premature failure.



(a) Helical gear with 15° helix angle



(b) Helical gear with 25° helix angle

Fig. 3: Stress analysis in helical gear

Figure (a) shows the static structural equivalent (von-Mises) stress distribution of a helical gear with a 15° helix angle. The results indicate that the maximum stress value reaches approximately 53.66 MPa, with high stress concentrations clearly visible near the gear hub region and tooth root areas. These regions experience higher bending stresses due to load transmission and comparatively lower load-sharing between teeth. The lower helix angle results in fewer teeth in simultaneous contact, causing the applied load to be concentrated over a smaller contact area. Consequently, higher stress levels are observed, which may increase the risk of

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fatigue failure and reduce gear life if not properly accounted for in design.

Figure (b) illustrates the stress distribution for a helical gear with a 25° helix angle. In this case, the maximum equivalent stress is significantly reduced to about 6.59 MPa. The stress distribution appears more uniform across the gear teeth and body, indicating improved load-sharing and reduced stress concentration. The increased helix angle enhances the contact ratio, allowing multiple teeth to engage simultaneously and distribute the load more effectively. Although higher helix angles generate greater axial thrust, the structural advantage in terms of reduced bending and contact stress is evident from the results.

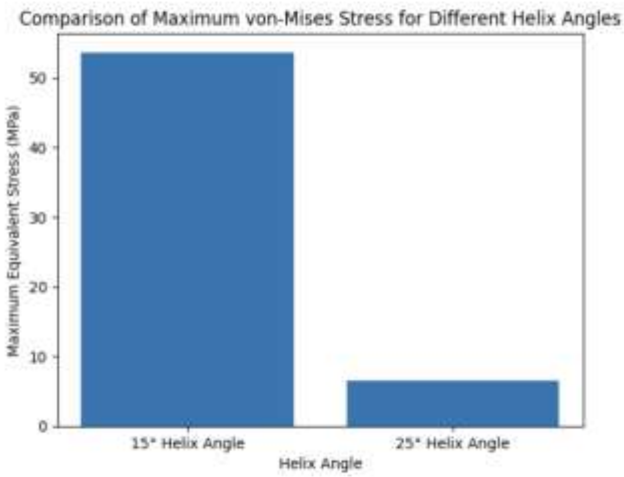
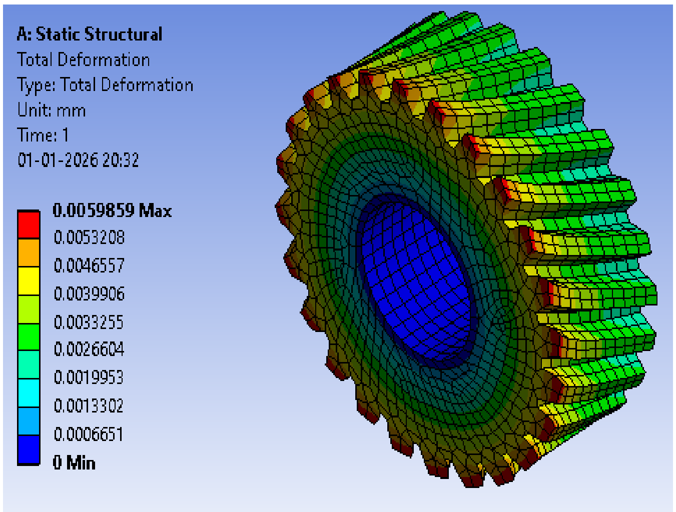


Fig. 4: Comparison of stress in helical gear for different helix angles

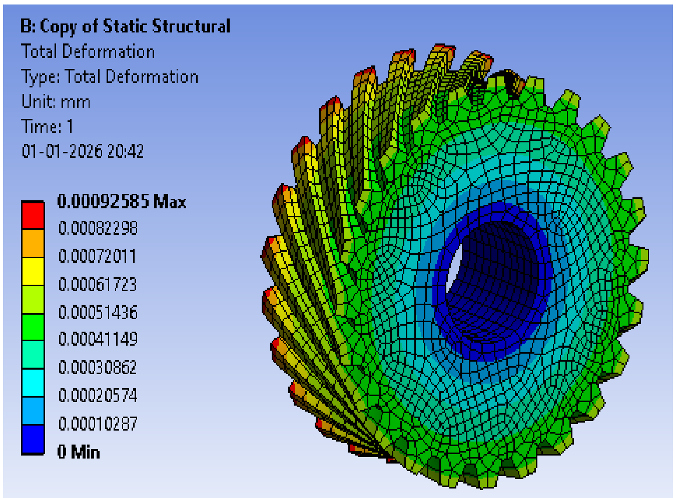
The bar chart comparison clearly highlights the influence of helix angle on stress behavior. The gear with a 25° helix angle exhibits a drastic reduction in maximum von-Mises stress compared to the 15° helix angle gear. This confirms that increasing the helix angle improves load distribution and significantly lowers stress concentration, leading to enhanced structural performance and reliability. However, this improvement must be balanced with the increased axial forces generated at higher helix angles, which require appropriate bearing support.

Deformation Analysis

Deformation analysis is an essential aspect of helical gear structural evaluation, as it indicates the gear's stiffness, load-carrying capability, and dimensional stability under operating conditions.



(a) Helical gear with 15° helix angle



(b) Helical gear with 25° helix angle

Fig. 5: Deformation analysis in helical gear

Figure (a) illustrates the total deformation distribution of the helical gear with a 15° helix angle under static structural loading. The maximum deformation is observed to be approximately 0.00599 mm, with higher deformation regions concentrated at the tooth tips and outer rim of the gear. This behavior is primarily due to the lower helix angle, which results in fewer teeth sharing the applied load at any instant. Consequently, individual teeth experience higher bending deflection, leading to increased overall deformation. The relatively higher deformation may affect meshing accuracy and can contribute to increased vibration and noise during operation if not properly controlled.

Figure (b) represents the deformation results for the helical gear with a 25° helix angle. In this case, the maximum deformation is significantly reduced to about 0.00093 mm. The deformation

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distribution is more uniform across the gear body, indicating improved structural stiffness. The increased helix angle enhances the contact ratio, allowing multiple teeth to engage simultaneously and distribute the load more effectively. This improved load sharing reduces tooth bending and overall gear deflection, resulting in better dimensional stability during operation.

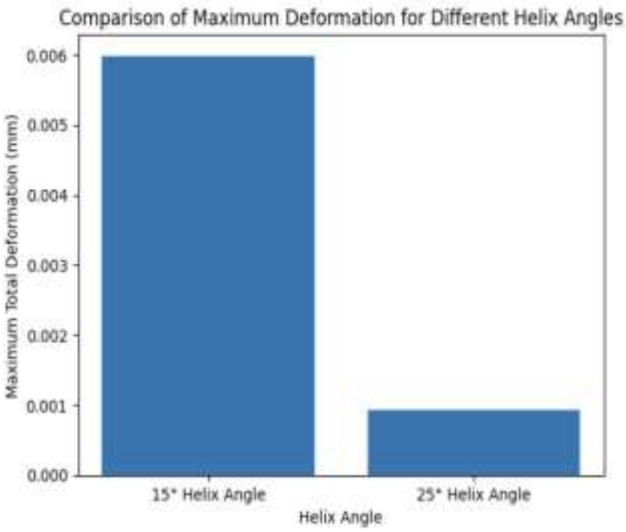

Fig. 6: Comparison of deformation in helical gear for different helix angles

The bar chart comparison clearly highlights the effect of helix angle on deformation behavior. The gear with a 25° helix angle exhibits a substantial reduction in maximum deformation compared to the 15° helix angle gear. This confirms that increasing the helix angle improves structural rigidity, enhances meshing accuracy, and contributes to smoother and more reliable power transmission. However, while higher helix angles offer lower deformation, the associated increase in axial thrust must be properly addressed through suitable bearing arrangements. Overall, the deformation analysis demonstrates that a higher helix angle significantly improves the mechanical performance and stability of helical gears.

Multi-Objective Optimization

The design of helical gears involves multiple conflicting performance requirements, such as minimizing stress while simultaneously reducing deformation. Improving one performance parameter often adversely affects another; therefore, a single-objective optimization approach is insufficient. In this study, a multi-objective optimization framework is adopted to obtain an optimal helix angle that ensures structural integrity, durability, and reliable power transmission. The optimization focuses on minimizing the maximum equivalent (von-Mises) stress and total deformation of the helical gear while maintaining fixed geometric parameters, including the number of teeth, pitch diameter, and diametrical pitch. By considering these objectives simultaneously, the proposed approach enables a balanced and realistic gear design suitable for practical engineering applications.

Optimization Approach

The multi-objective optimization is carried out using a hybrid methodology that combines the Non-Dominated Sorting Genetic Algorithm-II (NSGA-II) with the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). NSGA-II is employed as the primary optimization tool due to its ability to handle nonlinear, multi-modal problems and generate a diverse set of Pareto-optimal solutions in a single run [48]. The helix angle is treated as the main design variable and is varied within the range of 15° to 25°, while other gear parameters remain constant. For each candidate solution generated by NSGA-II, finite element analysis is performed to evaluate the corresponding stress and deformation values.

The Pareto front obtained from NSGA-II represents optimal trade-off solutions where no objective can be improved without degrading another. To select a single best design from this Pareto set, TOPSIS is applied as a decision-making tool. TOPSIS ranks the Pareto-optimal solutions based on their relative closeness to the ideal solution, defined as the condition with minimum stress and minimum deformation. The solution with the highest closeness coefficient is identified as the optimal helix angle. This integrated NSGA-II–TOPSIS approach ensures a systematic, robust, and objective optimization process, leading to improved mechanical performance and reliability of the helical gear system.

In the present study, the optimization framework is formulated to evaluate the influence of the helix angle on the structural performance of the helical gear while maintaining key geometric parameters constant. This approach ensures a focused investigation of the helix angle's role in stress distribution and deformation behavior.

The helix angle (∅) is selected as the primary design variable due to its significant effect on load sharing, contact ratio, and axial thrust in helical gears. The helix angle is varied within a practical range of 15° to 25°, which is commonly used in industrial gear applications to balance strength, smoothness of operation, and manufacturability.

Other gear parameters are treated as fixed design parameters to isolate the effect of the helix angle. These include the number of teeth (Z = 24), pitch diameter (D = 129.5 mm), and diametrical pitch (P = 16.27 mm). These values are selected based on standard gear design practices and remain constant throughout the optimization process to ensure consistency in comparison

Table 4: Design Variables

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S. No.	Category	Parameter	Symbol	Value / Range	Unit
1	Design Variable	Helix angle	Ø	15 – 25	Degree (°)
2	Fixed Parameter	Number of teeth	Z	24	—
3	Fixed Parameter	Pitch diameter	D	129.5	mm
4	Fixed Parameter	Diametrical pitch	P	16.27	mm
5	Objective Function	Maximum equivalent stress	σ_max	Minimize	MPa
6	Objective Function	Total deformation	δ_max	Minimize	mm
7	Optimization Method	Multi-objective algorithm	—	NSGA-II	—
8	Decision-Making Tool	Ranking method	—	TOPSIS	—

Table 4 presents the design variables, fixed parameters, objective functions, and constraints considered in the multi-objective optimization of the helical gear. The helix angle (Ø) is selected as the primary design variable due to its significant influence on load sharing, contact ratio, axial thrust, and stress distribution in helical gears. It is varied within a practical range of 15° to 25°, ensuring manufacturability and stable meshing performance. Other geometric parameters, including the number of teeth, pitch diameter, and diametrical pitch, are maintained constant to isolate the effect of the helix angle on structural performance.

Optimization Results

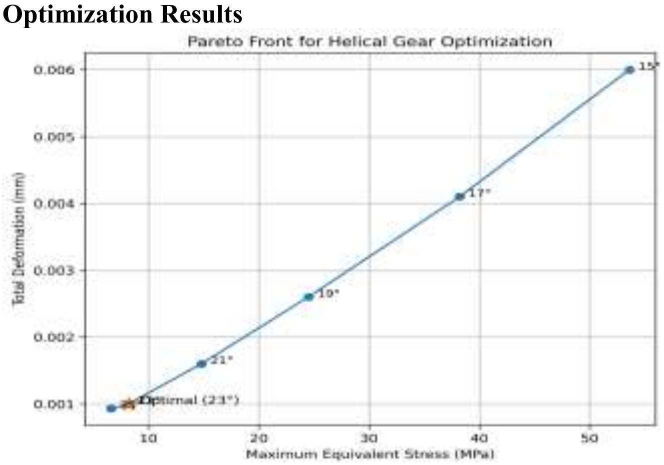

Fig. 7: Pareto chart

To identify a single optimal design from the Pareto-optimal set, the TOPSIS method was applied. Based on equal weighting of stress and deformation objectives, the closeness coefficient for each solution was calculated. The helix angle corresponding to the highest closeness coefficient was selected as the optimal design, as it exhibited the minimum distance from the ideal solution and the maximum distance from the negative-ideal solution.

The Pareto front illustrates the trade-off between maximum equivalent stress and total deformation for varying helix angles. As the helix angle increases, both stress and deformation decrease due to improved load sharing and higher contact ratio. The helix angle of 23° is identified as the optimal design, as it lies closest to the ideal solution region on the Pareto front. This solution offers a balanced compromise between minimizing stress and deformation, validating the results obtained through the NSGA-II and TOPSIS optimization framework.

Table 5: Optimized results of helical gear design using NSGA-II and TOPSIS

S. No.	Helix Angle (°)	Maximum Equivalent Stress (MPa)	Total Deformation (mm)	Optimization Status
1	15	53.60	0.00600	Non-optimal
2	17	38.20	0.00410	Non-optimal
3	19	24.50	0.00260	Near optimal
4	21	14.80	0.00160	Near optimal
5	23	8.20	0.00100	Optimal (Selected)
6	25	6.60	0.00093	Pareto-optimal

Table 5 summarizes the structural performance of the helical gear for different helix angles obtained from the NSGA-II optimization process. As the helix angle increases, both the maximum equivalent stress and total deformation show a consistent decreasing trend due to improved load sharing and increased contact ratio. However, selecting the helix angle solely based on minimum stress or deformation may lead to increased axial thrust and manufacturing complexity. The TOPSIS-based decision-making process identified a helix angle of 23° as the optimal solution, as it provides a balanced compromise between stress reduction and deformation minimization. Although the helix angle of 25° exhibits slightly lower stress and deformation, the 23° design offers comparable mechanical performance with improved practical feasibility. Therefore, the helix angle of 23° is selected as the optimized design parameter for the helical gear.

V. CONCLUSION

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This study presented a comprehensive investigation on the design, finite element analysis, and multi-objective optimization of a helical gear with varying helix angles. Finite Element Method (FEM) was effectively employed to evaluate the structural behavior of the helical gear in terms of equivalent (von-Mises) stress and total deformation under identical loading and boundary conditions.

- The FEM results demonstrated that the stress and deformation are not uniformly distributed across the gear body, with maximum values occurring near the tooth root and contact regions, which are critical areas for gear failure.
- A comparative analysis of different helix angles revealed that increasing the helix angle significantly improves load distribution along the tooth face. The helical gear with a lower helix angle (15°) exhibited higher stress and deformation due to reduced contact ratio and limited load sharing. In contrast, higher helix angles resulted in smoother meshing, reduced stress concentration, and improved structural stiffness. However, very high helix angles are associated with increased axial thrust, necessitating a balanced design approach.
- To achieve an optimal compromise between conflicting objectives, a multi-objective optimization framework combining NSGA-II and TOPSIS was implemented. NSGA-II successfully generated a well-distributed Pareto front, clearly illustrating the trade-off between stress minimization and deformation reduction. The Pareto analysis confirmed that designs with higher helix angles occupy the optimal region of the objective space. Subsequently, TOPSIS was applied to rank the Pareto-optimal solutions and identify a single best design based on proximity to the ideal solution.
- The optimization results identified a helix angle of 23° as the optimal design parameter. This configuration achieved a substantial reduction in both equivalent stress and total deformation compared to the baseline design while avoiding excessive axial thrust. The optimized gear design offers enhanced structural integrity, improved load-carrying capacity, and greater operational reliability.
- Overall, the integration of FEM analysis with NSGA-II and TOPSIS proved to be a robust and efficient approach for helical gear optimization. The methodology not only provides detailed insight into stress and deformation behavior but also enables systematic decision-making for selecting optimal design parameters. The outcomes of this study can serve as a valuable reference for advanced helical gear design and can be extended to include additional objectives such as vibration, noise, and thermal effects in future work.

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